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CONFIDENTIAL

STUDIES ON ADVANCED OVERSEAS ENERGY TECHNOLOGIES

Volume 1, Final Report

By

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March 1981

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Galaxy, Incorporated
Washington, D. C.



U. S. DEPARTMENT OF ENERGY

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VOLUME I

STUDIES ON ADVANCED OVERSEAS
ENERGY TECHNOLOGIES

FINAL REPORT

FOR

THE UNITED STATES DEPARTMENT OF ENERGY

IN ACCORDANCE WITH CONTRACT #DE-AC03-79SF10538

BY

Robert Ware Straus, Roy S. Thurman, Dr. J. N. Carsey,
Robert Pfeil, Dr. G. Von Bismarck, Dr. E. Spreen,
Dr. Fischer, Keith Bottomley, Dr. Chico Fujishima,
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March, 1981

VOLUME I

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CHAPTER I

INTRODUCTION

This final evaluation review covers investigations performed by Galaxy, Inc. over the past five years for the Department of Energy's Coal Utilization Division and its predecessor divisions, DOE's Power Systems Division and ERDA's Conservation Research and Technology Division. The effort has covered advanced energy work in Australia, the Middle East, Europe, Japan, Scandinavia and the U.K.

All task reports filed over that period of time were in response to specific subtasks assigned to Galaxy. The task reports, delivered as specified, might include as many as ten different subjects in each of the five or more overseas nations and were considered as "topical reports". Involved in the preparation of these task reports, in addition to the series of conferences with DOE officials here, were over 400 meetings in eleven nations, and a review of thousands of documents, many in the languages of the countries under study. The totality constitutes a review of some 100 advanced energy technologies over a time span which saw many new developments in energy conversion.

The changes in perception of energy conversion technologies in this five-year span have been tremendous. We know that technological leadership moved from Europe to the United States a century ago. But we now live in an interdependent world that America no longer dominates. We are now sharing the technological light with several other nations - and nations that only four decades ago we soundly defeated.

It is difficult to understand that we are losing our dominant place in the world within our lifetime. But within that same lifetime we have already seen this happen to other nations.

The economic growth of other nations enabled them to develop their scientific potential. Some are gaining rapidly in this field. Rather than being dismayed, we should be pleased. The results of energy conversion advances are universally available. Our only problem is to accept that which will help us - not reject the developments because they were "not invented here".

At this point, it is proper to acknowledge the hundreds of unstinting hours time granted to Galaxy's personnel by outstanding energy technology leaders and analysts in the public and the private sectors of the major technologically advanced nations. With only two exceptions over the years, they have been cooperative and helpful as any group in Galaxy's 30 years of practice in the field of international transfer of technology.

The purposes of this overseas effort were twofold:

1. To report on technologies which might be in advance of the state-of-the-art in the United States and might be available for use in meeting the energy crisis here.
2. The negative report, which might point out there were no technologies in advance of the state-of-the-art in R&D here, clearing the way for work to be undertaken here without violating the Congressional mandate about not "reinventing the wheel."

Our people in Washington, the U.K., Germany, Switzerland, Israel, Australia and Japan are gratified to have participated in helping solve the energy problems we all face.

We are particularly appreciative of the thoughtful help and guidance of Michael Perlsweig and Dr. Steven Freedman, DOE's Technical Project Officers for our work.

It is gratifying to report that over the years covered by this final report, the international understanding and respect for DOE's work has grown tremendously in almost all overseas nations.

CHAPTER II

SUMMARY AND CONCLUSIONS

This entire report is a summary of the thousands of pages of individual reports, and it is redundant to re-summarize here.

It is sufficient to recall that D.O.E. contracted with Galaxy to provide preliminary investigations to determine: first, if the state of the art for specified technologies; and second, if overseas work in developing these technologies, was or was not in advance of that in the U.S. In some cases, investigations revealed the U.S. technology development led the World. But, as the years passed, reports confirmed that in the overall, the U.S. was losing its leadership. This conclusion has been rapidly coming to the fore in national and Congressional interest.

Galaxy, because of its quarter Century experience in international transfer of technology, has been apprehensive on this point. In 1962, Galaxy's "Research in American Industry" report, analyzed the drop of research as a percentage of Gross National Product, and projected that by the mid 1970's, the U.S. might be losing its vaunted technology leadership.

While in the early 1960's, this warning was largely ignored, by the early 1980's it came to the center of the stage of U.S. debate.

The following table confirms the inevitable result of this lag.

ECONOMIC PERFORMANCE IN EIGHT COUNTRIES, 1962-1980

	<u>Real GNP</u>	<u>Productivity</u>
	(Avg. Ann. % Increase)	
1. Japan	7.9	7.8
2. Belgium	3.9	6.6
3. Netherlands	4.1	6.4
4. Italy	4.1	5.6
5. France	4.4	5.4
6. Germany	3.6	5.2
7. United Kingdom	2.3	2.7
8. United States	3.5	2.2

The amount of basic research performed by industry has dropped from 38% of the national total in 1956, to just 15% recently.

The changes now underway in American industry reflect some of the laboratory research which Galaxy reported 19 years ago. The drop in research since that

time indicate a bleaker picture ahead, unless changes are made in the innovative process here.

This problem is now drawing the attention of public and private sector officials; academe; and of rank and file citizens. The concern over our fall from technological superiority at the end of World War II, is a problem for all. Successions of presidential advisers have sounded warnings - few have prepared solutions.

Herbert Hollomon, with credentials in government, industry and academe, says "We have the NIH (not invented here) complex at the very time technological advances are coming from outside the U.S. As much as 2/3 of all R&D is now conducted by foreign laboratories. It should be of no surprise that they are taking the lead in such technologies as textile machinery and steel production." Mr. Hollomon concludes, "I believe other nations better understand that innovation processes are important."

It is clear that other nations are rapidly gaining. The United States no longer dominates.

Despite this, U.S. technological leaders at the 8th International Energy Conference in Washington, in

March, 1981, one after another, dismissed overseas R&D as "inconsequential," "derivative" or "not contributory".

Galaxy notes that the discrepancies between U.S. and overseas advanced R&D expenditures are already greater than the figures show. Approximately half of all R&D expenditures in the U.S. have been for military hardware or defense related projects, and under the new Administration, the military share will shoot up. While there is undoubtedly some 'fallouts' from such R&D, it is nowhere near as productive for technological advance as, let us say, the European technologies for energy saving in cement production; or the Japanese clear superiority in steel, the consumer goods, and electronics. An example is the awesome Japanese program not only in video tape machines, but an equally great effort to advance their gas turbine efficiency, which is aimed at putting a 50% more efficient machine on the international market, where 60% of the U.S. produced gas turbines are now sold.

We are now a low labor cost country, and, with few exceptions such as electronics, so considered by other high technology nations. The Germans now flatly state to Galaxy, "as far as we are concerned the U.S. is an

LDC, in regard to advanced technology." This is unpleasant, but we should take our medicine and get on with the business of rebuilding our leadership.

It is Galaxy's opinion that it will take at least five years to a decade to work our way back up. But it is important that we begin.

In making these assignments to Galaxy, DOE recognized these points. Galaxy's task reports from Japan, Germany, France, the Scandinavian countries, the U.K., and even Israel highlighted the advanced nature of specific technologies. The reports also showed the areas where no advanced work was being done overseas. This enabled the Office of Coal Utilization to proceed with the knowledge that we were not re-inventing the wheel. It reflected the directive of Congress in 1975, that funds supplied for energy R&D not be dissipated in duplicating work already done overseas. Thus, either a positive or negative answer in specific overseas innovations was of use to the various Technical Project Officers in planning their work.

There are, of course, many areas where the U.S.A. work is more advanced than overseas R&D. In some cases,

careful investigation revealed that overseas advances were based on U.S.A. developments.

DOE's task is not done. A change in direction, from the near term towards the 1990-2000 decade is a move in this direction.

In the course of our work in all of the nations covered, we have surveyed the expansive incentives offered by them to industry to encourage energy conversion technology advances.

These are summarized as a guide to steps that the U.S. might well adopt to increase our effectiveness in competing with other nations.

All nations surveyed provide tax incentives to encourage more energy productivity, particularly to use coal.

All nations have a stated policy on this subject, backed by parliamentary laws and defined by executive and administrative edicts carried out by government units.

All nations provide loans and grants usually at rates below the commercial loan market, or guaranteed by the government entity to accelerate commercialization of new technology.

All nations provide information, advice and subsidy, in one form or another for actual assistance in research and procedures for new energy source production and substituting alternative fuels.

All nations encourage use of waste heat, usually by cogeneration for district heating or over-the-fence sales to potential users through co-siting, brokering or other means.

All of these efforts consider fuel switching in the same category as straight energy saving.

All nations have made substantial strides toward increased substitution of coal, with the greatest gains made in the industrial sector.

Many nations have narrowed, and in some cases reversed the lead in industrial technology. This is shown in the following O.E.C.D. chart.

All nations believe that future progress will be harder to achieve, as the "quick and easy" gains have already been made.

Over the past five years, Galaxy has helped fabricate the network of communications with leading energy

‡ OF TOTAL GNP SPENT ON RESEARCH AND DEVELOPMENT

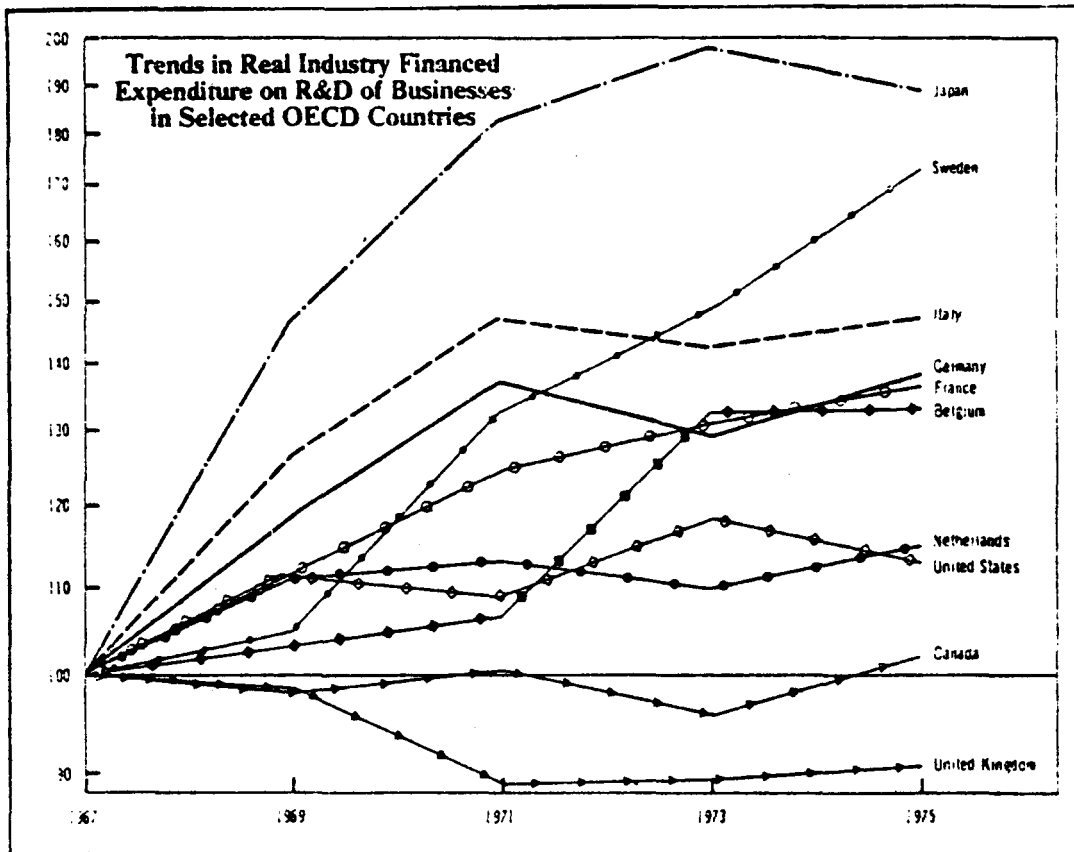
(Including military and space)

Country	Year	Total	Government	Industry
U.S.A.	'80	2.31	1.12	1.09
Japan	'77	1.72	.47	1.25
West Germany	'78	2.36	1.13	1.15
U.K.	'75	2.05	1.17	.84
France	'77	1.76	.93	.72

(Civilian only)

Country	Year	Civilian*	Gov't.	Business	Other
U.S.A.	'80	1.94	.76	1.09	.09
Japan	'77	1.87	.42	1.25	
West Germany	'79	2.18	.91	1.14	
U.K.	'75	1.39	.40	.84	
France	'77	1.35	.68	.72	

*Does not include military and space.



R&D institutions in the assigned countries. Our task is done.

DOE has the unique capabilities of keeping the circuits open so all may benefit from more efficient fuel conversion.

We are proud to have played a part.

CHAPTER III

SCOPE OF THE PROJECT & METHODOLOGY

Scope of the Project

This was clearly shown in a list of topical and special reports assigned to Galaxy, Inc. for research in overseas nations from 1976-'81, by the Office of Coal Utilization and its predecessor Divisions.

This list was reviewed in early 1981 with the Technical Project Officer. He indicated those subjects which are still rated as "priority" and "for emphasis and follow-up" in relation to current DOE programs. The selected technologies are CAPITALIZED. It will be noted that the same priority items re-occur over a number of reports, sometimes in different areas, and also for specific follow-up.

However, this list does not include letter reports; conferences with Project Officers concerning their special field of endeavor; telephone reports as a result of critical information telexed from our overseas offices; or symposia and workshops in which Galaxy was directed to participate.

1976 Memorandum Review of Specific Targets, April 26, 1976

GAS TURBINES - ceramic blades

- blade cooling

- FT-50 turbine

- fuels--synthetic fuels

--low carbon/hydrogen

- combustion chambers

- heat exchangers

Pump Technology -

COMBUSTION - Japanese stratified charge

- Industrial burners

Materials - FUEL CELLS - metal catalysts

- alternative electrodes

- new acid electrolytes

- utilization of waste

materials - recycling plastics

- RFP for metals

Bottoming Cycles - Automatic production (lasers)

- Small steam turbine

- organic fluids

- Brayton cycles
- Stirling engine
- HTFS (U.K.)
- Screw type compressor

Industry Conservation/Unit Operation/Distillation -

- high temperature recuperation using silicon carbide in the steel industry
- DRY COKE QUENCHING
- HIGH TEMPERATURE BLAST FURNACES
- distillation technology
- industrial heat pumps
- FLUIDIZED BED COMBUSTION OF COAL
- Drip irrigation in Israel
- Milk sterilization
- Industrial baking ovens
- Hot deboning

Waste Treatment - Activated carbon treatment
system

Memorandum Review of Specific Targets as redefined -
June 8, 1976

Bottoming cycles - add: Japanese Ranking bottoming
cycle engine (IHI).

Heat Transfer, Topping Cycles - diesel waste heat recovery
- silicon carbide & silicon
nitride heat exchanger
- fiber reinforced tubes

First Monthly Technical Report - June 28, 1976

Literature review for first "Round-the-World Review".

Second Monthly Technical Report - June 6, 1976

Preparations for "Worldwide Field Review".

First Quarterly Report - July 27, 1976

Some preliminary findings on the items assigned.

Third Monthly Technical Report - August 9, 1976

Preliminary findings from Australia, Japan, Switzerland

Fourth Monthly Technical Report - September 10, 1976

Patterns emerging from the intensive field review follow fairly closely the forecast indicated in the earlier reports for this project.

Annual Report - December 10, 1976, which reported:

Primary Objectives - GAS TURBINES; Industrial heat pumps;
- STIRLING ENGINES; Diesel waste heat recovery

Secondary Objectives - CERAMIC MATERIALS; COMBUSTION;
- FLUIDIZED BED COMBUSTION;
- Organic fluids; Small steam turbines below 100 h.p.; Pressure retarded osmosis; Reverse electro dialysis;
- Energy storage.

Agricultural and

Food Technologies - Drip irrigation; Industrial bread & cake baking ovens; Hot deboning; UHT sterilized milk.

1977 First Quarterly Progress Report - March 8, 1977,

covering:

Components and

Heat Engines - Ceramic Heat Exchanger (Stirling
Engines), German Few Megawatt
Rankine Cycle Engine,

- GAS TURBINES BURNING HEAVY RESIDUALS

Heat Utilization - Internal Total Energy Systems and
Load levelling for Individual
Buildings; Long Distance Trans-
mission Low Grade Heat (Sweden,
Finland)

Fuel Cells - Fuel Cells, Drop Molten Carbonate,

- Substitute Proton Conducting Electrolytes;
- Fundamental Electro-catalysis, particularly
Correlation Catalysis and electro-catalysis;
- Alkaline Fuel Cells

Combustion and Fuels Technology:

- Methane recovery from coal beds and abandoned mines;
- IC Engines;
- Gas Turbines;
- Boilers to burn liquid fuels at 0% excess air;
- Industrial process burners for energy conservation

Materials:

- High purity silicon carbides & nitrides (Japan);
- Non destructive ceramic testing

Thermodynamics and Heat Transfer:

- Determination of sulfur dew point in diesel stacks;
- Fluid to extend temperature range of domestic and commercial heat pumps;
- Joint technology exchange program on heat transfer; HTFS, HTRI, (U.K.) and UMD;
- INFORMATION ON EQUIPMENT AND TEST RESULTS OF RESIDENTIAL FLUIDIZED BED COAL COMBUSTORS AT TNO (HOLLAND)

Agricultural/Industrial/Commercial Applications:

- Drip vs. spray irrigation;
- Coal vs. oil fired industrial bake ovens;
- Acetylene ex coal (Germany);
- Thermo Chemical chlor-alkali production;
- Waste heat recovery from steel slag;
- Gaseous sterilization of food;
- Nitrogen fertilizer production improvements;
- Paper/Head Box Paper and freeze concentration of black liquor;
- Textile foam dyeing and finishing and hyper-filtration of dyes.

Second Quarterly Progress Report - June 3, 1977

Progress on priorities set form in First Quarterly Report, 1977 (above)

Third Quarterly Progress Report - September 8, 1977

Modifications in Previous Assignment Priorities:

Add: Friction reduction through improved lubrication and better bearings;
New control mechanisms needed for breakthroughs in fuel cells; heat cycles and combustion.

Eliminate: Heat Utilization;

- Long Distance Transmission of
Low Grade Heat
- Thermodynamics and Heat Transfer;
- INFORMATION ON EQUIPMENT AND TEST
RESULTS OF RESIDENTIAL FLUIDIZED
BED COAL COMBUSTORS AT TNO-HOLLAND.

List of major priorities slightly revised order.

Included report from Japan on "Sunshine" and Moonlight"
Program.

Fourth Quarterly Progress Report - December 9, 1977

Extensive Modification of Assignment Priorities.

Efficient Energy Utilization through Tribology Research -
Advanced R&D in lubrication friction and wear of
mechanical components.

Components and Heat Engines:

- CERAMIC HEAT EXCHANGER;
- Gas turbine tailcones;
- Bearing supports;
- STRUTS AND TIP SEALS;
- Ceramic turbine blades in actual commercial use,
- SULZER'S THICK CERAMIC BLADE COATINGS;
- EXTERNALLY FIRED REGENERATIVE GAS TURBINES

Heat Utilization:

- Waste heat recovery;
- COLD RECOVERY FROM GASIFICATION OF LNG;
- Internal total energy systems and load levelling for individual buildings;
- Organic Rankine cycles and bottoming cycles

Thermodynamics and Heat Transfer:

- Determination of sulfur dew point in diesel stacks;
- Working fluid to extend temperature range of domestic and commercial heat pumps.
- Joint technology exchange program on heat transfer via HTFS - HTRI (U.K.) UMD

Combustion and Fuels Technology:

- Methane Recovery from coal beds and abandoned mines;
- IC engines to burn lean;
- DIESEL NO_x;
- Gas Turbines - meet U.S. standards NO_x control without water injection.
- BURN SYNFUELS WITHOUT NO_x EMISSIONS;
- BOILERS TO BURN LIQUID FUELS AT 0% EXCESS AIR;

- Industrial process burners for energy conservation;
- Utilization of wood residue fuels;
- Residential up through small industrial application;
- DIRECT COMBUSTION;
- PYROLYSIS AND GASIFIER SYSTEMS;
- FLUIDIZED BED - BOTH AFB AND PFB AND HOT GAS CLEAN-UP

Further Follow-up on Agricultural/Industrial/
Commercial Applications:

- Drip vs. spray irrigation;
- Coal vs. oil fired industrial baking ovens;
- New processes for acetylene ex coal;
- Gaseous sterilization of food;
- Nitrogen fertilizer production;
- Paper-Head box paper and freeze concentration of black liquor;
- Textile foam dyeing and finishing and hyper filtration of dyes;
- SMALL AUTOMATIC COAL FIRED BOILERS;
- Energy saving on alfalfa drying via proxan process in France.

This report also included a detailed report on the Japanese THERMOEXCEL HEAT TRANSFER SYSTEM.

1978 Fifth Quarterly Report - March 1, 1978

Review Progress to Date on Follow-Up Technology Evaluation.

Also includes reports on CIMEX, the U.K. National Coal Board; Transfer of Technology, and Energy Workshops in U.S.

Sixth Quarterly Report - June, 1978

Continued Follow-Up Evaluation, including a section on Cement Plants.

Seventh Quarterly Report - September, 1978

Continued Follow-Up Evaluation; including first phase of an investigation of the Hierarchical Computer Control System, developed by Nippon Steel Company of Japan.

Biennial Report - December, 1978

Complete Review of the Two-Year Findings, with Recommendations.

1979 Task #001 Report - "Survey on R&D in Japan of Selected Energy Saving Technologies", July 20, 1979

Including:

- Recuperators;
- Industrial heat pumps;
- Improved oil or gas burners and furnaces;
- Advanced cogeneration;
- IN SITU MEASUREMENT METHODS FOR PARTICULATES, SUCH AS FLY ASH OR FLUIDIZED BED MATERIAL, ETC., OR OTHER STREAM POLLUTANTS IN GAS TURBINES.

Trip Report - June 15, 1979

Preliminary reports covering Tasks #001 and #002 of this Contract.

Task #002 Report, "Additional Research on Advanced R&D in Japan", August 1, 1979

Including:

- High temperature recuperators for industrial waste heat utilization;
- Industrial heat pumps;
- Improved oil and gas burners and furnaces;

- Advanced cogeneration - district heating from central power stations or industrial sources from solid wastes;
- Heavy fluid turbines to utilize heat from gas turbines and diesel exhausts;
- IN SITU MEASUREMENT METHODS FOR PARTICULATES SUCH AS FLY ASH OR FLUIDIZED BED MATERIALS, ETC.

Trip Report - September 15, 1979

Preliminary Data for Task #004 of this Contract.

Trip Report - October 30, 1979

Covering second trip for Task #004 of this Contract.

Task #004 Report, "Preliminary Field Review Updating European R&D Efforts", November, 1979 (9 countries).

Including:

- HIGH TEMPERATURE GAS TURBINES;
- COMBUSTION;
- Heat Exchangers;
- ADVANCED HIGH TEMPERATURE AND CORROSION RESISTANT MATERIALS;

- Waste heat recovery and utilization;
- COGENERATION INCLUDING TOPPING AND BOTTOMING CYCLES;
- Long distance heat transmission;
- IMPROVED OIL AND GAS BURNERS FOR INDUSTRIAL AND COMMERCIAL APPLICATION.

Task #005 & 005A Reports, "Organic Rankine Cycle Engine Technology in Japan", October, 1979. (#005)
"ORC Engine Technology in Europe", November, 1979 (#005A)

Including:

- (005) - Recovery of Waste Heat from Cement Plants.
- (005A) - Linde Germany ORC Waste Heat Recovery, Spanish Development of Solar Powered Rankine Cycle

1980 Task #006 Report, "Executive Summaries of British Energy Council Reports"

Including:

- U.K. oil shales;
- Energy R&D in the U.K.;
- Advisory Council on Energy Conservation;
- Energy: the key resource, and
19 additional energy papers.

Task #007 Report, "Source and Availability of Hollow Spheres"; January 8, 1980.

Including a Special Report on Borsig A.G., (covering 7 countries.

Trip Report, October 10, 1980

Preliminary report covering Tasks "008, 009, 010, and 011 of this Contract.

Task #008 Report, "SURVEY OF EUROPEAN TECHNOLOGY DEVELOPMENTS OF SO_x/NO_x FLUE GAS CLEAN-UP FOR COAL FIRED BOILERS; ALSO FREE PISTON STIRLING ENGINES AND COAL TAR BURNING DIESEL ENGINES", October, 1980 (4 countries).

Task #009 Report, "Update on Specified European R&D Efforts", October, 1980.

Including:

- SHELL KOPPERS PROJECT;
- STATUS OF THE AFB PLANT;
- Enkoping, Sweden;
- NE, FB Super Heat System;
- Flat Non-Swirl Blue Flame Burner;
- FRANCO TOSI - RESEARCH ON COMBUSTION OF SARDINIAN HIGH SULFUR COAL;

- SIXTH INTERNATIONAL CONFERENCE ON FLUIDIZED
BED COMBUSTION;
- CARBOGEL;
- ENEL (Italy) ELECTROSTATIC PRECIPITATOR;
- DC Spike for Removal;
- KONGSBERG (NORWAY) RADIAL INFLOW TURBINES;
- BMFT (German) High Temperature Carbonization;
- Studsvik (Sweden) High temperature corrosion work;
- 100-200 MW Nuclear ORC (France);
- FIAT (Italy) Totem heat pump;
- ANSALDO (ITALY) LOW COST HEAT EXCHANGERS FOR
DIESEL WASTE HEAT RECOVERY;
- GUTEHOFFNUNGSHUTTE STERKRADE AG, (GERMANY)
GAS TURBINES.

Task #010 Report, "Advanced Processes for Metallurgical
Coke", December, 1980.

Including West Germany, France, Japan, Sweden and
Austria.

Task #011 Report, "Evaluation of the RWE (Germany) Desulfurization Process for a Lignite-Fired Generating Station", October 1980.

Including:

- A description of the basic process data and the economics of the process;
- Arranging for a one-day joint meeting at RWE with Messrs. Hoy and Challis of the U.K., assigned by DOE, who separately reported on application of the RWE combustion and boiler design to American boilers and other technical aspects of the RWE project.

Task #012 Report, "Evaluation of the Steinmueller Desulfurization Process for Coal-Fired Utility Boilers", (Germany), December, 1980.

Including:

- The basic process strength, the weakness and the economics, in cooperation with Galaxy-Planco's retained combustion flue gas expert, Dr. Fischer; and such information as the state of the development at the present time, and planned progress.

1981 Task #013, "Specific Advanced Overseas Technologies for Coal Burning IC Engines in Europe", (Germany, Denmark and Sweden), March, 1981.

Including:

- An update of the results of the study on the subject matter of 1975/76 and preparing conclusions and recommendations to DOE with respect to R&D in the field of coal-burning IC engines, beginning with proposed attendance at the First International Symposium on Coal Burning IC Engines, organized by the German Federal Association of the Aviation Accessory and Rocket Industry in Bremen, Germany, if held prior to February 1981. Since the conference did not meet the deadlines, Galaxy prepared a brief report on the present status and readily obtainable comments by German experts, reviewed by Mr. Soehngen, the author of the original 1975/76 DOE report.

Task #014 Report, "Update on the State of the Japanese Fuel Cell Program", February 10, 1981

Including:

- Phase I AN OVERVIEW OF THE JAPANESE PROGRAM.
- Phase II A detailed report on non-confidential aspects of the technology, should Phase I reveal a substantial Japanese program.
- Since Galaxy advised that it would not be cost effective to proceed with the full-scale Phase II, a drastically reduced Phase II, covering the advanced work in one or two Japanese institutes may be indicated.

Task #015 Report, "Investigation of the Saarbergwerke Fluidized Bed Feeding Gas Turbine Project"- Federal Republic of Germany, March, 1981.

Including:

- An investigation and status report setting forth the available detail on the work being conducted by Saarbergwerke at their plant near Saarbrucken, FRG, in which fluidized bed combustor gas is cleaned and heated by oil to provide the input for a turbine.

Methodology

Galaxy's standard operating procedure always includes some literature search here and further clarification with the Technical Project Officer. The assignment is then transmitted to Galaxy's overseas associates in the country or countries specified in the assignment. They produce preliminary reports which are usually discussed with the Technical Project Director. Thereafter, if necessary for coordination of final data on comparative technologies in different nations, a Galaxy senior from the Washington office visits the pertinent corporate headquarters and/or government department, universities and also the laboratory or plant site where the technology is actually being developed, tested or used. In many cases specialists in specific technologies are asked for their professional opinions and comments.

The final reports are reviewed and edited in Washington. The conclusions and recommendations are solely those of the Galaxy senior staff, who have decades of experience in the international transfer of technology.

For clarity and continuity in this final report, there has been a regrouping of various priority assignments under unified headings, which are self explanatory.

Those subjects which are no longer priority to DOE, either because of the technology has been transferred, the problem solved, or a change in Departmental goals, are treated only briefly.

It should be borne in mind that in no case was Galaxy requested to study, review and report on U.S. technology. The state-of-the-art in U.S.A. was supplied by others. However, on a number of occasions Galaxy was directed to participate in symposia, workshops and discussions on subjects under study.

BIBLIOGRAPHY

A final report of this nature normally includes a full bibliography of all technical papers assembled from overseas sources and submitted to DOE.

Compiling a bibliography of the hundreds of papers and data sheets on different subjects appended to the more than 30 formal reports submitted; the letter reports and conferences for which additional material was submitted, would not be cost effective. This material is on file at the Oak Ridge Technical Information Center and elsewhere in DOE with the appropriate reports. Therefore, these are included in this final report by reference to the original reports as submitted.

CHAPTER IV
COMBUSTION

Introduction

In the earlier years of the overseas investigations, this subject was given lower priorities than some hardware items such as gas turbines, heat exchangers, etc. Also, as goals shifted and became better defined, general investigations of IC engines were dropped as was methane burning.

In recent years, emphasis was primarily directed toward coal combustion with minimal environmental damage. Included in the tasks were fluidized bed coal combustion, both AFB and PFB; lignite and peat combustion, even wood combustion and a range of advanced combustors from small sized to residential sized; utility sized furnaces and steel mill combustors, including coke production, particularly dry coke quenching and high temperature blast furnaces.

It is assumed that the reader is familiar with the procedures of the International Conferences on Fluidized Bed Combustion, which list in detail some of the overseas work initially reported in brief as part of our tasks.

Also included in this array for more recent reports were coal dust burning diesels and coal-oil mixtures as well as coal water slurries. Obviously, some of the combustor work that are closely associated with the hardware, such as gas fired turbines is included in that chapter. Duplication has been eliminated wherever possible.

Small Combustors

Early tasks called for coal or wood burning bake ovens. The investigation showed that direct combustion (rather than pyrolysis) was considered the optimum route in Europe.

The technology of Gebruder Weiss in Germany, a firm specializing in small package sized combustors and furnaces turned out to be ready for transfer, and was recommended to DOE. A DOE expert was dispatched to negotiate with the Weiss firm, and Galaxy was relieved of further responsibility.

TNO in the Netherlands tests on the Fluidfire patented residence sized combustor was investigated. The hardware was originally designed so that the bed material would act as an automatic damper for gas and oil-fired burners to prevent heat loss when the flames were shut-down. However, the R&D of Buderus' sche Eisenwerke in Wetzlar with Preussag AG Ibbenbüren had advanced this into a complete automatically fired residential sized coal burner with automatic ash removal and storage for disposal by the same truck which delivered the coal. At that time, there was no further interest evinced by DOE, and the project was not pursued.

Small Automatic Coal-Fired Boilers

100-600 Horsepower

Galaxy reviewed this matter in France, Germany, Switzerland, Belgium and the Netherlands.

In Germany, and in the low countries, we were informed that such boilers had existed, but the trade in them had virtually disappeared with the greater availability of lower priced gas and liquid fuels.

One company, Schoppe, A.G. in Munich was reported to still offer such boilers. Catalogs and specifications were delivered.

However, interest in this field is reviving. The FRG Ministry of Science and Industry is moving to "increase the utilization of primary energy and reduction of emission with fully automatic, grate-fired solid fuel heat generators. The work was assigned to Buderus' sche Eisenwerke in Wetzlar, with Preussag, A.G. Ibbenbüren. Dr. Nichel is the project leader."

The project calls for development of a fully automatic operation, without supervision at all loads, with adequate pollution controls.

They tested a 100,000 kilocalorie per hour unit, as the engineers believe this is the smallest capacity which they can successfully design. They tested anthracite, bituminous and sub-bituminous coals.

The best results are with anthracite and brown coal coke, "because the reactivity of the brown coal coke is fairly high, and makes a good safe deliverable fuel with good burning conditions."

The aim is a small boiler which will operate at least 24 hours "without supervision, with the truck delivering the solid fuel also automatically, recovering the ashes."

Gasification & Combustion of Wood Residues

There were also early task assignments concerning utilization of wood products. There has been a sharp increase in the use of wood-burned products in Europe - mostly based on the burning of bark. The experts explained "there are much more valuable uses for chips and sawdust than other residues".

Again, Gebruder Weiss in FRG had a good small packaged boiler and some packaged wood-fired boilers based on grate burning.

In Germany, Volkswagon was working on gasification of wood-waste products and the conversion of methanol as an automobile fuel.

In Sweden, Volvo was also doing advanced work based on gasification and conversion to methanol.

In Norway there was considerable advanced R&D at NTNF to use powdered wood as a fuel. The obvious drawback was the highly explosive characteristics of the finely divided wood powder. The Norwegians solved the problem by storing the powder under an entirely nitrogen atmosphere in order to forestall additional danger of explosion. This was not followed up for further recommendations as the tasks were changed.

The Glomers Company in Switzerland was doing some pelletizing of wood residues for fuel.

However, the above alternate fuels did not seem to be substantially in advance of the technology available in the U.S.A., and the tasks were being narrowed to the combustion of coal.

Fluidized Bed Combustion

The development of this promising technology has paralleled to span Galaxy's work.

By the end of 1978 attention was directed toward fluidized bed combustion on large scale. This interest was continued up to the final work under the contract, and was fortified under the proposed programs to meet the directives of the new administration in 1981. Galaxy's tasks included the fluidized bed developments in Japan, West Germany, the Scandinavian countries, Italy and Spain.

The following review of the work in Europe and Japan brings the state-of-the-art up to the end of 1980, and projects some milestones in 1981.

Galaxy in 1976 identified the fluidized bed work in the U.K. as "one of the more promising technology transfer areas". It appeared as one of the U.K.'s strongest areas, divided as follows:

1. Large utility work through the National Coal Board.

2. Stone-Platt Fluid Fire Limited, offering commercial fluidized bed combustors up to 2000K BTU/hr.
3. A new company established a little later called, Flameless Furnaces Limited, primarily concerned with small rather than large fluidized bed work.
4. Work at Rolls Royce on fluidized bed combustors to feed gas turbines.

Dr. G. W. Bundrett of the Electrical Council Research Center, Capenhurst, Chester, CH1-6 ES, England, has been able to reduce the size of the fluidized bed combustion to a small industrial scale for boilers of 5 megawatts or even for home use.

After discussions with such experts as Professor Jack Howard of the University of Aston in Birmingham and others, Galaxy recommended follow-up on each of the above. The work on utility size boiler-burners became the subject of a joint DOE/NCP project. This superseded Galaxy's part of the work in that area.

Europe

Higher efficiencies in combustion with lower deleterious wastes has increasingly become a major subject in European R&D.

Even small countries like Norway and the Netherlands (both with new found off-shore petroleum and gas supplies) as well as Italy and Spain (without domestic oil and gas supplies) are mounting sizable fluid-bed programs.

All European countries are watching the Grimethorp and similar multinational developments with PFB as a possible way toward commercialization.

As could be expected, Germany with substantial coal supplies and a renowned technology R&D base was doing very advanced work. Galaxy's early reports on Bergbauforschung, Ruhrkohle-Deutsch Babcock, Shell Koppers, were absorbed by direct contractual relationships between DOE and the organizations mentioned, both through international and bi-lateral agreements. These mechanisms were the conduits for the transfer of technology to the appropriate U.S. agencies and bodies. There were numerous reports on the extensive German RD&D program; only the more recent specific items are repeated in this summary.

Germany

A. Saarbergwerke AFB

Mr. Mayer, Project Manager of AFB described this project.

"Air is heated to 700°C with the aid of an AFB. This temperature is raised to 850°C with methane, before the air drives the turbine. Exhaust gas from that turbine serves as an oxidizer for the AFB. The hot gas from combustion generates steam for the steam turbine." Subsequently, this project was reviewed by the FFU Technical Project Officer.

B. Ruhrchemie AG

In response to Galaxy's question of how many hours of operation, Ruhrchemie's Dr. Ruprecht reported: 2,500 operating hours, input 6 tons per hour; output 10 Nm³ per hour.

C. Shell-Koppers Process in Hamburg

Mr. van der Linden, Project Manager, Mr. Vöckel Head of the department, "Coal and Coal Gasification" of Shell, responded to specific questions, stating the gasifier has been built and is coal fired. The coal input is about 150 tons per day, to be raised to 1,000 TPD within the next few years. The plant is financed by private funds, with some additional funding through the EC, currently being negotiated.

D. Ruhrkohle - Deutsche Babcock AFB

Mr. Speck, Project Manager stated Ruhrkohle was operating a prototype plant of 35 MW; coal input 6 tons/hr.; steam generation 50 ton/hr.; pressure 17 bar; temperature 400°C. The plant has been operating since March 1979.

Mr. Speck, in response to Galaxy's questions in March 1981, reported that the plant was still on stream, had a 75% availability during 1980, and was running "to full specifications".

In addition, Mr. Speck outlined the following data:

- A. Main objectives in this project are the optimization of heat transfer, combustion temperature and desulfurization.
- B. For desulfurization, 7% limestone is added to coal before coal injection.
- C. The plant is operated with low levels of carbon in the FB (carbon concentration is 1% rather than 10%).
- D. The combustion temperature range is approximately 800°C - 900°C.

Sweden

The AFB at Enköping turned out to be a complex situation.

Enköping is a town of 40,000, some 50 miles from Stockholm. It has a district heating system with over 80% connections to a central heating plant. Like the nearby Vasteras, combined power and district heating plant (previously reported by Galaxy) it is municipally controlled, but unlike Vasteras it is not a cogeneration plant.

It is a 25 megawatt station. The major boilers are a standard oil fired burners supplied by Kymi Kymmene Engineering of Helsinki, Finland.

However, there are Swedish Government funds, supplied through NE, to provide one fluidized bed boiler.

The FB basic design was mostly done at Studsvik by McHugh's group.

Kymmene did not have the experience with FB and sub-contracted that boiler to Mustad in Norway, who made the FB installation.

It was originally designed as an oil fired AFB, but during the project, was converted to a system which could burn oil, coal and supposedly peat, biomass and even municipal waste.

The standard type boilers apparently work satisfactorily.

However, the AFB originally designed for high sulfur oil was then tested on coal. At the time of Galaxy's inspection in August, 1979, it had about 5 days of continuous firing on oil, but it had only about 8 to 10 hours on coal.

Essentially, the combustion takes place in the 10 meter high AFB. The hot gas is carried over into a down-draft heat exchanger and economizer, and at the bottom of this there is a set of small trap doors to take out the large particles which are around 1/4 inch in diameter. The gas then goes through another heat exchanger and ends up in a bag plant, where the bags are cleaned by pulsated air.

The best that Chief Engineer, Mr. Osterberg would say was, "come back in a year and we'll see how we do next winter when there's a real load on it."

Bryan McHugh is in charge of the fluidized bed work at Studsvik. He explained that they have a 250 kilowatt unit at Studsvik. They were working on the design of a 2-1/2 megawatt unit. This is to be a precursor to scaling up to a 25 megawatt unit.

They were having difficulties in throttling it down, and could not get below 20 megawatts output. They described their Mustad boiler as about the same as Battelle's multi-heavy fuel type. He was of the opinion that their designs could be used for industrial waste with a catalyst. He said their pyrolysis test was similar to that of Erco-Cambridge.

The supervisor of this program is Lars Stromberg of Studsvik. Lars Stromberg informed us in early June 1980 that the plant has been working experimentally in the winter of '79/80, but has not been commissioned by Mustad,

the responsible company due to major changes of the basic AFB layout. In the course of these changes, the FB will also be converted for coal combustion as originally planned. According to Stromberg, the severe problems had been solved and a decision about commissioning was expected for July. After that the conversion for coal combustion is planned.

Mr. Osterberg, the directing engineer of the plant yielded the following results:

Operation

Except for the few hours that the plant operated with coal in '79, the plant has not operated on coal. Several fundamental problems within the combustion process had to be solved by the responsible company, Mustad of Norway. The only operation since August '79 lasted for 2 weeks in May. High sulfur oil (2.9%) of the heavy type was burnt.

The base plate of the fluidized bed had to be completely redesigned. The nozzles were newly developed by the Technical University of Trondheim in cooperation with Mustad. In addition, the heat exchanger within the bed was redesigned, since the area of the original version was too large. Fundamentally, the system is designed for processing of various fuels; if peat is used, however, the limitation will be set by the existing bag filter, which cost \$48,000 - \$72,000 and is not expected to handle the emissions, so no experiments with peat are currently planned.

The addition of dolomite was run at a stoichiometric ratio Ca/S of 1.2, corresponding to 200 kg of dolomite per ton of oil. The objective of this successful experiment was to determine if the ratio was sufficient to meet the SO₂ emission standard. Under these conditions Osterberg claimed a reduction of SO₂ flue gas content by 57%. An independent environmental control authority, (a company INKAD), did the emission measurements for the town of Enköping and also measured the particulate emission passing the bag filters (supplied by Bahco).

Osterberg called the company asking for the measurement results which then were not released. It was the impression that the specified limits for particulate emissions which for Enköping were stated to be 1.5 g/kg oil, were not met in the trial runs. Osterberg cited very favorable particulate emissions well below 1 g/kg oil, measured in the spring of 1979.

The main problem of the plant and the reason for delayed commissioning and acceptance by the town of Enköping is failure to meet the specifications. This has to do with reaching the specified output power of 25 MW, and achieving maximum power between 21 and 22 MW, if exceeded, ash meltdowns occurs forming pellets that wear down the ducts.

During the subsequent visit to the plant, where fine dust was visible everywhere, Mr. Osterberg complained about perforations of the ducts as results of experiments aimed at achieving the maximum power.

It is still planned to convert the system to coal, however, a maximum power of only 15-17 MW is expected since the system is limited by the flue gas volume

which is higher for coal than for oil. As a result, the maximum thermal efficiency will be in the range of 75%-80%. Currently, a specification for the operation with coal is worked out in cooperation of Wärmewerke, Mustad and Studsvik. In a later portion of the interview, Mr. Osterberg conceded that he foresees big technical problems with coal, but would not specify details. As a possible solution he suggested to inject the coal particles in two ways, depending on particle diameter: the small particles directly into the bed, whereas larger particles would be injected on top of the bed. Also, he foresees problems in meeting the emission levels for SO₂ with the Polish coal (25 tons of Polish coal were deposited on the yard of the Plant).

The originally planned grinding facility at the plant is no longer necessary, if the aforementioned new coal feeder will process particle sizes up to 30 mm Ø, with a special device called a spread stoker. Presently, the coal feeder can only process particle sizes up to 4-6 mm Ø.

In October 1980, Jackie Bergman of NE informed us that NE was currently not working on this project, while it might be continued at Stal-Laval or the Varvet Shipyard in Uddevalla.

Mr. P. E. Larsson of Stal-Laval, Development Manager of the Marine Division, stated that the project was in full swing in a joint venture with Babcock and Wilcox.

The objective of development calls for an oil/(coal)-fired fluidized bed in the 20 MW range to be applied both in ship- and power plant turbines. The power plant version is to be coal-fired. This FB technology in turn could then be usable for coal freighters (range around 100,000 tons) to be solely powered by a fluidized bed boiler.

The concept shall be applicable to land use for boilers up to 300 MW.

The status of the development program is characterized by 2,000 hours successful test bed operation of an experimental system in the range of 1.2 MW, stated to be "full sized in some aspects". Stal-Laval is currently

negotiating with a shipowner to test a version of this plant on a ship. The subsequent step is the design and test of a 20 MW-system in a steam plant.

Other types of fuel, i.e. coal, are stated to have been tested with positive results.

Stal-Laval is pursuing the policy of rejecting public support for this project to save their technical rights; interest was expressed, however, to initiate contacts with DOE.

In the field of pressurized fluidized bed work, Stal-Laval is cooperating with AEP Inc., U.S.A., on a combined cycle plant of 300 MW.

Mr. Stig Sögren of the Varvet Shipyard mentioned various projects underway there on energy saving in ships, involving organic Rankine cycles as well as fluidized beds, heated by the exhaust gas of large diesel engines, i.e. fluidized bed heat exchangers. Thus, their work is closely related to the Stal-Laval FB project, which is currently evaluated by Varvet in a study. Sögren indicated that the temperature on the steam side was more around 600°C (rather than 750°C to 800°C).

Jackie Bergman at NE reviewed other FB work in Sweden as follows:

The Institute of Technology in Gothenberg planned a full sized coal AFB, with a 15 megawatt thermal capacity. The contract calls for operation in late 1981 to provide steam for a turbine. The district heating system which will be fed by a back pressure system will supply the Technical University. This is part of an IEA project.

Generator AB has fast fluidized bed for municipal waste. They have an advanced 6 megawatt system for preparing the waste. It already has full test operations with wood-waste. It uses cyclones and bag filters to clean-up the gas.

Maskinenverken made an installation in a power plant, based on coal and wood waste. This is a research unit - 2 megawatt in size and obtained good results.

NE supported a fluidized bed for oil-fired super heat systems to provide 750°C to 800°C super heat for ship turbines.

Related FB Work in Sweden

Jackie Bergman is in charge of thermal conversion work at the Swedish Government Board for Energy Source Development (NE) at Spunger, outside Stockholm.

The government sponsored program is directed toward a fast fluidized bed to burn the coal to produce low BTU gas. They began with a small unit about one foot in diameter and 10 meters high. It was not completely successful. It was similar to the work at the Hydrocarbon Research Institute in the U.S.A. He considered work to be the same, having the same problems such as ash agglomeration. They use Polish coal, but they do not think their test bed is coal sensitive. They use a bed of O+ash in the steady state, starting with 100% coal. They are aiming at a program for retrofitting boilers.

In March 1981, Galaxy was informed that the Enkoping plant results were essentially negative and the plant was being rebuilt, to be ready in November 1981 for coal. Also, two additional plants elsewhere were succeeding with wood chips.

Interview with Prof. Rolph Collin

At the Royal Institute of Technology

Galaxy had interviewed Professor Collin in 1976 and 1977 about his flat non-swirl blue flame burner with a non-luminous flame.

Prof. Collin had been looking for a manufacturer. He still doesn't have one.

However, he had a program to work the burner on heavy fuel oil (American #5) with an NO_x of 50 parts per million.

He still claims that his flat non-swirl burner compared to ordinary burners produces a higher transfer of heat.

He is proposing to work on his burner using pulverized coal, coal-oil mixture and also wood.

He is also doing some work with compressed air atomizer and testing the burner on coke oven gas to use a 10% CO in the heat treatment furnace (25 to 30 burners).

Collin is working on a small fluidized bed project of 400 millimeters with money from ENI. With this small size equipment, he is scaling to retrofit steel reheat and steel heat treating installations to use coal. It is a two-step process - fluidized bed on the bottom and a blue flame on top in a 100 ton furnace.

Galaxy arranged for Collin to meet with the DOE technical project manager in 1980. It quickly became apparent that he still seeks funds for actual commercial production and test.

Denmark

The public sector work was reviewed at the Danmark Tekniske Højskole (Technical University of Denmark) at Lyngby near Copenhagen.

The university team was led by Prof. Dr. Knud Østergaard (Head of the Chemical Engineering Department); Prof. Svend Hadvig (Head of Mechanical Engineering), Prof. Dr. Bjorn Qvale (Head of Energetics) also an IEA team leader and various staff members.

The Technical University in cooperation with the Danish Department of Industry has a small (0.25 MW) fluidized bed furnace as a demonstration unit to carry out combustion experiments with coal and other solid fuels, including waste materials; to study combustion efficiency; turn-down properties, ash properties; sulfur retention by Danish limestone; nitrogen oxide formation and heat transfer to submerged pipes.

Polish and South African coal is the main source of electricity and district heating use is bound to increase. Their coal program is in three branches. The first is the fluidized bed work at the Technical University. The second is coal prospecting in Greenland and elsewhere. The third branch is the private sector, carried on mostly by private enterprise through the Danish Boiler Makers Association (Dansk Kedelforming).

The fluidized bed work is aimed at a few years ahead, and they are working up know-how for sale elsewhere in the world.

Hadvig is working on an oil burner to burn 1/2 kilo per hour in a blue flame no soot, to be used in a two temperature boiler. It recaptures stack gases in a gas-liquid heat exchanger at 70°C for water out and 40°C for water in, claiming 20% more heat out of the oil.

There is no installation or test completed.

Burmeister & Wain Damp
(Steam Division) at Virum

Galaxy consulted with Vice President Knud Bendixon and Ing. Director Vagn Kollerup at the Virum Headquarters of the firm producing ship turbines, diesels etc., as well as boilers before its distribution.

It should be noted that the parent firm went bankrupt in 1980. The boiler division was acquired by LENTOES Konzern of Dusseldorf, FRG, which Kollerup reported in 1981, "now allows intensified work on fluidized bed boilers."

B&W have quite a bit of experience in fluidized bed work. They are working on installations for fossil, (oil and coal, brown coal) oil shale, bark, waste wood and bagasse.

Their only operating commercial plant is the Ringe district heating plant. This was a commercial scale demonstration plant to provide actual operating data. The

plant has two 4.7 MW fluid bed boilers, with 1.6m X 1.6m; vertical fire tubes and bag filters. Coal is fed by a conveyer. The operation is computer controlled.

In March, 1981 Mr. Kollerup of B&W responded to Galaxy's Hamburg office update questions that they had stopped all work on the 5 MW/PFB project, but their 10 MW AFB south of Arhus would be on stream in April 1981.

F.L. Smidth Co.

Smidth is at Valby, south of Copenhagen. The company specializes in engineering design and construction of cement plants. Their Chief Engineer, Ernst Ellergaard told Galaxy, their designs for combustors do include atmospheric fluidized beds. However, their work appeared to be mostly state-of-the-art, and ancillary to their cement line.

Finland

The fluidized bed work in Finland emphasizes the use of peat - their only domestic fossil energy source.

In both the public and private sectors, there is a good deal of work going on, and some commercial FB installations.

DOE's Drs. Miller and Kopstein were preparing an on-site report on peat extraction and combustion in Finland. To avoid duplication, their report is included by reference.

In the public sector, Professor Antero Jakkola at the Helsinki Technological Institute, has a 250 KW AFB test rig designed for peat.

In the private sector, Ekono Oy, set up by the major pulp and metal working industries, provides for the pooling of Finland's limited resources for R&D.

Ekono occupies a building in Espoo, near Helsinki, of which Otaniemi is part, and is located on the campus of the university. It currently has 1,000 employees.

Galaxy's proctor for the visit was Pentti Rouhiainen the Manager of Energy Planning.

The first interview was with Lars Ahlström, Ekono's burner and boiler man. They have designed and supervised construction on a number of fluidized bed plants. When asked about the sizes, it was 200 tons per hour of waste wood and bark.

Ahlström said his greatest contribution was a combination, oil and wood burner. He provided a diagram of a slanting bed wood burner adjunct on the side of a boiler which could burn oil. He demonstrated the advantages of their type of slant bed wood burner with differential air injection.

He says it's more expensive in capital cost, perhaps twice as much as for the equivalent firing rate. He states the advantage is that it is much easier to control excess air and a fast pay-back period.

This concept was developed further by Timo Korpela, Head of Ekono's Power Plant Engineering Department.

Korpela explained the Ekono system for paper plants of firing oil, wood and waste liquors simultaneously with coal. He detailed that Ekono has followed a different path than the U.S.A., which favors travelling stokers and spreaders. Finish practice uses several furnaces feeding a single boiler.

Korpela claims the new aspect of their work is in pre-drying of feed material. By this, they can lower the flue gas temperatures from 450°C to 200°C , and the fuel drying is making a breakthrough in Scandinavia. He feels that low temperature drying below 500°C to 200°C is much better because it doesn't drive out the hydrocarbons.

At the largest plant in Sweden, all stack gases are passed through dryers, removing 85% of the water. The resultant material is like gun powder and highly explosive (see Norwegian Experience). They avoid explosions by having all the material kept in "a sealed tube" atmosphere. Despite the expense of the system, they find its pay-back is less than three years. This new plant will be ready and go on-stream this year.

On fluidized bed, Korpela claims Finland has a new approach. The bed material is carried away in the gas stream, but is recoverable. He calls this the "pyroflow method". Using bark as part of the fuel, they run it through a high temperature cyclone at 900°C and then bring back the fluidized bed material. This new design is an Ahlström patent. The detailed design data is incorporated by reference, as it has been delivered to DOE.

Ing. Kaulamo then gave design details of the inclined grates for wood burning. They are self controlled; self feeding by gravity; easy to control combustion; use a variety of fuels and maintains a higher temperature. The only drawback is that it may result in a reducing atmosphere, which causes some difficulties.

It should be noted that Ahlström OY of Finland has a 15 MW fluidized bed combustor in operation. As this has been reported by Miller and Kopstein, who studied peat in Finland just before Galaxy's visit, it is included in their report and omitted here.

France

France is short on fossil fuels. Coal, petroleum and gas resources are extremely limited. Her gas comes mainly from North Africa. Her coal is located in two areas, Pas-de-Calais, Lorraine, and some small coal fields in the "Centre et Midi". 75% of all energy is imported.

France has gone the nuclear route. By 1985 they will have an installed nuclear capacity of 40,000 MW, covering 50% of their electrical production, and it will be growing with new nuclear reprocessing plants coming on stream.

France's major efforts were directed towards energy conservation. They claim success, having achieved less TPE either per capita or per ton of industrial product.

Mr. Zyss and Mr. Maillard of the Agency for Economizing Energy (AEE) described to Galaxy some of the combustion work the agency is supporting. AEE is driving toward commercialization in the mid '80's. They subsidize 50% of the cost of demonstration projects of commercial size, and widely disseminate the operating data of 100 projects now launched.

AEE's fluidized bed work is directed mainly towards urban wastes, primarily for district heating in co-combustion with other fossil fuels. The only example which Galaxy visited was on the Left Bank in Paris, near the Eiffel Tower, where an urban renewal area of high-rise office, apartment and hotel buildings was heated, cooled, etc., by a central station.

Charbonnage de France, Cherchar Industrie Division is responsible for R&D. When questioned by Galaxy, Michel Fournier stated that Cherchar supported advanced fluidized bed combustion research, but due to the dwindled coal supply in France, this is receiving no priority. The same was true of synfuels from coal.

There is some work on gas fluidized beds, but it is mainly carried on through Gaz de France, in collaboration with Sweden, according to Mr. Robert Vincent of Gaz de France.

Netherlands

The Netherlands has a solidly active FB R&D program.

Although not primarily based on coal as a fuel, a 4 MWAFB is under construction in Apeldoorn, based on a 2M x 1M bed area, with evaporation cooling (15 bar). The details furnished to Galaxy by TNO state:

Program of Activities

- To construct of 4 MW atmospheric fluid-bed boiler at Apeldoorn.
- To make preparations for experiments in this furnace to test the environmental impact of different kinds of coal under practical conditions.
- To adjust the research program to meet the requirements of the Dutch industry.
- To intensify contacts with sponsors, if any.

Combustion & Combustion Plants Aim

- To ascertain the condition for the optimum combustion of sewage sludge and municipal refuse or fractions thereof in a fluid-bed incinerator.
- To collect practical data on emissions from combustion plants.
- To get an insight in diverse aspects essential to the safe functioning of combustion plants, like flame guarding and NO_x generation.

Program of Activities

- To determine the optimum conditions for combustion in a fluid-bed incinerator of sewage sludge with 40% dry matter, to carry out investigation on the diverse process parameters and the aspects of heat economy, capacity and environmental impact, and on proper pretreatment of the sludge.
- To try to restrict NO_x generation in fireboxes by burner modification and flow investigations.

- To evaluate flame-guarding equipment.
- To construct a measuring arrangement for flare investigations and conduct the appropriate measurements.
- To contribute to the insight in the effect of SO₂ emissions on air quality.

Complete data is scheduled to be available in late 1981.

Another Dutch potential was in the flameless furnaces, small fluidized bed work, based on a zone system with three fluidized beds operating as one, and a system for ash removal. Galaxy reported on a test conducted by TNO in the Netherlands, and recommended follow-up.

Italy

Italy has no coal except for small quantities of low grade, off the coast in Sardinia. They also have no oil and no gas.

Despite this, and despite Italy's reputation of general economic and social malaise, there is a booming economy (4.3% GNP growth against Germany's 1.0 and U.S.A.'s 00.01), strong currency, good exports, and a feeling of going ahead on R&D.

Despite the fact that about a third of the private sector economy is "underground" from the government, both executives and researchers were willing to discuss their work, and a good deal of innovative energy R&D is going on in Italy.

Through the courtesy of various combustion experts in the U.S.A., Galaxy talked with leading researchers in both the public and private sector. However, it must be recognized that through a maze of interlocking companies, some fully government owned, some half government and half private, and some private, there is no hard fast division.

At the academe level, Dr. Luigi di Luca at the University of Milan, and the combustion group at Naples University, with Dr. Antonio D'Alessio and Professor Massimiliano, Head of the CNR group, are doing advanced work on fluidized beds. This work is reflected in efforts of their colleagues, and in some of the quasi-public-quasi-private groups gathered under ENI. These are too numerous and too complex to report here, except to note that the same work may be reported by several different institutions all of whom may have a hand in a project, and/or be working on different aspects thereof.

For example, in one organization ~~Cesen~~, all members of the Ansaldo Group are in turn related to IRI, which is state owned and/or financed, and in turn the members of this group have financial and other interests in companies controlled by Fiat and other Italian private sector companies. Also, engineer Radaelli of Franco Tosi sits on the Boards of many of these companies representing his company's interests. Furthermore, the various Ansaldo group companies themselves overlap to some extent, which furthers the problem. In another organization the officers explain "CISE leaps out in its complexity".

All this is to point out the difficulty of identifying to the outsider just who is doing what and where, and who is paying for it.

Despite the almost impenetrable forest* of organizations involved, the division of responsibility, work is accomplished and an export boom in energy conversion equipment is taking place.

Dr. Luigi di Luca at the University of Milan is primarily a combustion man, who had been working in rockets and now in diesel combustion. His overview of the work at various institutions in Italy was most helpful. He stressed the work of Professor Massimiliano, Head of the CNR combustion group and the School of Engineering at Naples; the people at CISE, CESEN, CEN, FIAT, and the newly organized "Institute Guido Donegani", formerly the Research Division of Montedison, now headed by Ezio Colombo.

CISE, a "think tank", an offshoot of ENL, employing 600 people, is an impressive laboratory set-up outside Milan. They are doing no AFB or PFB work, but considerable research in materials, corrosion, fouling, utilization of energy sources, which is treated elsewhere in this report.

*Identified by Italians as Dante's "Selva Oscura".

Franco Tosi at Legnano, southwest of Milan, was an equally impressive institution. Ing. Luciano Radaelli, Vice Director General, flanked by Paul Cavelleri, Director of Research, and others were detailed for interviews.

On FBC, they were presently doing leading FB research with the Italian Associates Institution of SNI, which is part of ENL. They have built a small prototype with a 1 meter square bed. This is designed to burn the only Italian coal from Sardinia. It has a very high sulfur content of 5-7%. This prototype was to be on stream by the early '81, and is considered just a test bed. They are considering "the stability of flames and the density of feed-air, emissions, etc.

Meanwhile, they are proposing a 20 megawatt atmospheric fluidized bed for a generating station. This is a joint venture with Breda.

Galaxy's European associate made the offer of testing Sardinian coal at Morgantown to Ing. Luciano Radaelli. Ing. Radaelli referred the matter to Professor Paris at ENEL, who in turn referred it to Dr. Tacchino at the Italian Ministry for Industry, who referred it to Breda.

The coal was eventually shipped, delayed in Baltimore for many months to determine a customs classification. However, at this point Galaxy's task was completed.

On advanced combustion and coal-oil mixtures, they are working with Exxon.

On coal utilization, they are contributing to the IEA project. The Institute for Economics for Energy (IEFE) at the University of Milan is doing the work.

They are doing no work in hot gas clean-up in fluidized beds. In SO₂ removal, they are purchasing the technology abroad now, but as noted, beginning their own program.

The FIAT group, with their strong development work in gas turbines and in diesels, turns out to be doing little in combustion per se, but their broad based program (covered in other chapters such as "Turbines", "Materials", "Heat Recovery", etc.) should be noted.

In Genova, CESEN (Centro Studi Energia) part of the Ansaldo Group, proved to be doing some FB work. This is primarily directed at using the high sulfur, low grade Sardinian coal, with only 2,000,000 tons production in 1978. It involves coal-oil mixtures as a way of solving these problems. This turns out to be a paper study of overseas technologies. In fact, they dispatched a Mr. Butoni for six months to the Pittsburg ETC to catch up on U.S.A. work.

Nuovo Pignone in Florence, is Italy's only other gas turbine manufacturer. They are working only on new heat exchanger manufacturing technologies that may be of some future use in FB work. They appeared to be looking for a license while conducting a feasibility study based on the Lurgi fixed bed process, in order to make an overseas tender.

At Pisa, the Centro Ricerche Termiche Nuclear of ENEL provided some interesting R&D work. Dott. Ing. Georgio Dinelli, Chief of the New Techniques Department led his colleagues through a group of far out uses of compressed air, electrostatic dual precipitations, etc.

Dr. Rossi of the staff is conducting a study of heat flux, using hot gas as the source. This includes field testing of an extensive mathematical model program and modification for tangentially fired boilers. Apparently all analyses have been on high velocity swirling radiant fired flames.

Drs. Serpio Ligasacchi and Giancosimo Grazzina are designing a 1 megawatt AFB. It is so designed that it can be converted into a 15 atmosphere, 15 megawatt pressurized fluidized bed. Prof. Massimiliano at Naples is collaborating.

Meanwhile, they have a 10 centimeter diameter AFB now running to determine the best dolomite. That's one thing Italy has plenty of.

Their plans show a double wall with tubes in between, to heat the input air.

Drs. Ligasacchi and Grazzini are using cyclones to clean the output and are working mainly on combustion and corrosion in the bed. They are aiming to use only the

heat for steam, and hope to finish construction in 1981. They state, "the vessel is already built", and hope to install it as a unit in the LAVORNO power plant in the future.

Drs. Ligasacchi and Grazzini have not done any work at all in feeding a hot gas from fluidized bed to turbines and do not plan to do any for at least several years.

Spain

It was not anticipated that Spain would produce any startling domestically generated combustion technologies, due to their limited supplies of coal, their limited capital available for new plant installation, and the emphasis on solar work.

D. Luis Perez Prat had just become President of Babcock & Wilcox Espanola, S.A. He was until recently Director General of the "Bienes de Equipo-INI", which is the Spanish Government Energy Holding Company, Capital Equipment Division.

However, despite his B&W presidency, he was unacquainted with any work on fluidized bed combustion, or FB heat exchangers.

Sr. Juan Regidor Arribas, Subdirector of Auxini Investigation Aplicada of INI is a solid technical man. He is directing a short-term program - aimed at the next 2-3-5 years, first to establish the needs, then to proceed to meet them.

On fluidized beds, they are at work on a project to use asphalt as the feedstock for hydrogen, gasoline and ethanol. This project is being undertaken in the laboratories, and also working on extracting minerals, such as uranium. (cf the Galaxy report from Sweden on the FB work on uranium).

They are experimenting with any organic fuel as a feedstock, ranging from biomass through urban wastes to plastics, to produce hydrogen or ethanol, based on the Fischer-Tropsche reaction. The first pilot plant based on 1 ton per day throughput is on-stream in Southern Spain.

Sr. Muniz Turr-albo is The Centro De Estudios de Energia's lead man for information. The results were:

1. FB work is being developed with Foster-Wheeler technological backing at the National Carbon Laboratories at Oriedo.
2. Coal-oil mixtures - being worked on at UNESA, again with Foster-Wheeler's help.

Portugal

Portugal is in the same energy squeeze as the rest of Western Europe, with growing trade deficits due to petroleum prices.

65% of Portugal's electric power is hydro. Like Spain, Portugal has a limited supply of low grade coal (40% ash) and large supplies of lignite, which they are beginning to develop.

Ing. Sidonio Paes, Director General of Energy in the Ministry of Energy described their efforts.

There is no FB work in Portugal, but there is coal-oil mixture work underway. The lead organization in this field is Mague Estrecia National in Alveca. They supply the Electricidad de Portugal (EDP). However, it turned out they are Foster-Wheeler licensees on boilers, and Brown Boveri (Switzerland) licensees on turbines.

They are currently working on some 300 megawatt units for a CINES plant of Electricidad de Portugal (EDP) to use 50 micron pulverized coal and they are working

on coal-oil mixtures to use the Portuguese low quality coal, but first would use U.S.A. imported coal. The technology as described by Director Bettencourt was well up with similar technologies in the U.S.A. and elsewhere, but not in advance thereof.

Mague does no FB work, no gas turbine work, but is working at 1,000°C in steam. They would not elaborate on this without a Secrecy Agreement.

TERMEC is also in the boiler-burner-heat exchanger, etc. field. Macedo Pinto of TERMEC states they have produced some multi-fuel boilers to use coal, cork, eucalyptus wood, or butane or methane gas.

TERMEC is launching a program on environmental clean-up of the stack gases from their boilers, but so far this is paper research.

Professor Veiga Simoa, Director of the National Laboratories of Energy and Technology (LINETI) stated they were working on fluidized beds, but the size was small. LINETI has 1,000 people in its laboratories at Sacavem, north of Lisbon. But as Director Simoa delicately put it, "they have just been reorganized, not yet settled down."

In summation, Portugal appears to be a market for U.S. combustion technology, rather than a source.

Japan

In 1979, Galaxy reported on the thrust of the MITI Sunshine Project. At that time, Japan was just beginning to move into the fluidized bed area, with a pressurized gasification system based on high calorie coal, coal gasification at the National Research Institute for Pollution and Resources with Hitachi as a contractor; a multi-purpose fluidized furnace to treat waste and regenerate used activated carbon, which as then still on a laboratory scale; and a project administered by MITI's Coal Bureau aimed at low calorie gas production in a pressurized, fluidized furnace. This work was scheduled for construction and on-stream in 1981 - which is beyond the scope of Galaxy's contract.

Other projects for pressurized, fluidized bed gasification, calling for 5-ton-a-day initiating projects at Yubari Coal Mine in Hokkaido to be stepped up to a 40-ton-a-day pilot plant, engineered by Mitsubishi Heavy Industries and others to go on-stream in 1981, with an application study for at least two-years and a 100-ton verification furnace to be built later on in the 1980's.

From there, the Japanese outline schedule calls for these pilot plants to be constructed in the 1985 Fiscal Year, and 1987-'88 for the prototype plant. However, these latter dates are subject to the caveat, "the schedule will be very fluid". It is Galaxy's conclusion, from long experience in Japan, that they will fairly well adhere to this schedule.

Governmental and private sector organizations, as well as descriptions of the various R&D projects in Japan were provided in detail in Task #002, which is incorporated herein by reference.

Additional Japanese combustion work on coal tar burning diesel engines and coal-oil mixtures are treated under those headings later in this chapter. The related Japanese flue gas clean-up work is covered in the chapter, "Pollution Control".

Coal-Oil Mixtures,
Coal-Water Slurries, Etc.

Galaxy has reported on the development of these combustion materials a number of times during the overseas investigations.

In 1978, Galaxy reported on the state-of-the-art in Japan (see pages 5-11, Fifth Quarterly Reported dated March 1978).

As part of the MITI development project of coal utilization, Japanese study on COM started in 1975 with the leadership of the National Research Institute for Coal.

The Electric Sources Development Company, a private concern, is a central figure in the research. One of the cooperative enterprises involved is Mitsubishi Heavy Industries, Ltd. The final objective of this project is to produce 30 t/hr of COM (equivalent to 100,000 KW) and establish relative technology to make test burns by 1981. This project is subsidized by the Government.

A pilot plant was prepared for producing one t/hr of COM at the Nagasaki dock of Mitsubishi Heavy Industries in early 1978, allowing economic data to be studied and collected.

The purchase of the attritor milling equipment from Union Process Company of the U.S. by Mitsubishi Heavy Industries formed part of this project. Mitsubishi conducted pilot tests with an array of auxiliary equipment in addition to the milling machine. The data on the cost of pulverization and powder consumption was collected beginning in 1979. The projected application is for power plant fuel. No diesel fuel is under consideration in this project.

COM would be prepared by mixing oil and coal with the ratio of 1:1, with a stabilizer to be added to prevent coal from settling while COM is stored or transported. It is predicted that pulverizing coal into too fine a particle would not be economical. A grain size of about 75U for the pulverized coal firing would be used. Studies on the stabilizers under these conditions has been made with a certain degree of success.

It is expected that possible applications would be power plants, steel manufacturing (blast furnace injecting fuel), cement calcining kilns, and any air-heating equipment now burning oils. Various kinds of coal ranging from anthracite to lignite are considered possible. Mitsubishi Heavy Industries contemplated that COM plants will be constructed at coal mining locations, unloaded via pipeline, stored and then used as fuel, thus eliminating the conventional equipment for unloading coal and availing free scope for selection of power plant locations.

Another program is to develop 'coarse particle COM'.

As the target date for completion of this R&D program in Japan is 1981, Galaxy recommends follow-up on this program as it develops, as considerable data will be available.

As this report goes to press, the following information up-date was received from Dr. Fujishima of Galaxy-NJM in Tokyo.

Coal-Oil Mixture (COM)

As we reported previously, the R&D of COM is formally carried out by a governmental agency named The Coal Mining Research Center, Japan, but actually the program is practiced by Electric Power Development Company with some leading Japanese boiler manufacturers and chemical companies who participate in the program, under the MITI research grant as well as an aid system of research expense.

Development Schedule

The program commenced as scheduled in fiscal 1976, to end in fiscal 1983, with two projects, COM for electric power plants and COM for blast furnaces.

Respective schedules are as per the following table:

	*	'76	'77	'78	'79	'80	'81	'82	'83
<u>Electric Power Development Co.</u>									
Step I	Basic tests	←→							
Step II	Pilot basic tests (1 t/H)	←→							
Step II'	Pilot practical tests			←→					
Step III	20t plant practical tests								
	A Coal-burning thermal generation					←→			
	B Oil-burning thermal generation					←→			
<u>Blast Furnace</u>									
Step I	Basic tests			←→					
Step II	Practical furnace tests					←→			

*Please note that these are Japanese fiscal years.

The Progress of the R&D

The progress has been favorable. The result attained in the fiscal 1979 was presented in detail at an international COM symposium. It should already be in the DOE system and is not reflected here.

The result of the fiscal 1980 study is scheduled to be detailed at a meeting in Florida, U.S.A., April 1981, too late to be included here.

Based on the schedule, the COM basic technologies for production, storage, transportation and combustion have been already completed through the Step I (basic study), and Step II (1 ton/hr pilot plant). Now the run is entering into the Step III, practical tests, where an actual 20 t/h plant is almost finished, scheduled to start up in this April. These tests will be undergone with a boiler for a coal-burning thermal plant of 250,000 KW at Takehara Power Station. This means COM use for coal-burning boilers is already, technically, almost perfected. The Tokyo Electric Power Co., Inc. plans to build a 5 million t/y COM center.

In contrast, COM use in oil-burning boilers is technically more difficult and requires one year and a half for designing, one and a half for construction and one year for operation tests. Since 1980 the design has been studied and working drawings are underway.

The basic study of the COM used for blast furnaces started in the 1978 fiscal year and is completed now. Actual tests of blowing into a blast furnace is currently underway. The tests are made in a Sumitomo Metal Industries plant, and the results are being compiled as this report goes to press.

Effects of COM Development

The COM under the current study is characterized by a maximum 50/50 ratio of coal/oil, 70%-80% of pulverized coal of less than 74 micron and 8,000 KCal/Kg of heat value.

The effects of using COM are:

1. All grades of coal from anthracite to lignite (including fine slack) are usable, which fact is helpful to the efficient utilization of coal resources.

2. Large quays and facilities for unloading coal can be omitted; only large scale of facilities for unloading oil is required.

3. The quantity of oil required for thermal power plants burning, currently in operation is reduced. Also, plant location will be less rigid and more wider selection of sites is possible.

4. There is possibility of application to various oil-burning equipment, such as cement kilns, air conditioners, paper-pulp processors, blast furnace injectors, etc., so that dependency on oil is minimized.

The result of the study has already developed to such an extent that electric power companies can now plan their specific utilization of COM. In order to popularize COM, a 3-year investigation program to determine demands for COM, location of COM centers, distributing organization, etc., is being carried out.

Government Aid Systems to COM Development

Government subsidization and expense aid systems with respect to COM R&D are as follows:

a) COM subsidy is furnished from the budget for new coal-utilization technology as follows: (Please note these are Japanese budget years)

	1979 1980	1980 1981	1981 1982
Electric	\$366,320	\$2,814,800	\$2,636,540
Blast furnace	106,040	1,362,060	1,378,520

The actual funding of R&D is 1.5 times in the electric research program and 2 times in the blast furnace research, of the above subsidiary payment. The rest is paid by each company. MITI has designated the above subsidy for the Coal Mining Research Center.

b) The MITI 100% subsidy for developing the technology of COM use at oil-burning thermal power plants are as follows: (Government assigned tests on reliability verification).

1979-'80	1980-'81	1981-'82
0	\$1,619,520	\$1,605,060

The tests are performed by Electric Power Development Co., Ltd.

c) The MITI 100% subsidy for the study of COM center location was budgeted as follows:

1979-'80	1980-'81	1981-'82
0	\$149,420	\$197,620

The New Energy Development Organization also carries out the study.

Norway

Norway now has North Sea oil and Spitzbergen coal. Up to the present, hydro has supplied most of their electrical power, but the limit of development is approaching.

Thus, the Central Research Institute is working on COM, oil-water mixtures and jells, as well as collaborating on FB work.

While not in the direct line of coal-oil mixtures of the specified sizes, the work on powder combustion technology deserves some mention, as it is being closely followed in some other European countries.

Dr. Rolph Edoff, Director of the Christian Michelsens Institute in Bergen told Galaxy of his years of work on powdered fuels technology. He is working on extremely finely divided powders, with particles so fine that they have explosive properties, and must be kept in controlled atmospheres. The three-years systems analysis has been completed. The Technical University at Guthenburg is undertaking laboratory pilot plant trials.

While originally based on biomass, his work is being extended to peat, lignite and low grade coals, as well as COM.

Sweden

Galaxy first reported on Scaniainventor, a Swedish research firm in 1978. At that time, Scaniainventor claimed the development of "Carbogel", a fluid fuel, consisting of about two thirds coal with water and minor addition of a chemical agent.

Their claims for Carbogel were:

1. Can be handled by pump in enclosed systems.
2. Easily transported in tankers and stored in tanks.
3. Can be burned as oil with minor modification of the burner assembly in an oil fired furnace.
4. Can be altered to allow pumping into high pressure reactors, fluidized beds and be used in chemical processes.

5. Can be purified of inorganic sulfur, heavy metals and ash, by grinding prior to mixing.
6. By removal of considerable impurities of coal, the addition of water does not result in direct increase in transportation volume, compared with mineral coal, which initially contains 10% water.

Galaxy requested technical information, which Scan-
lainventor refused to release, asserting that "they were
in the process of preparing important patent applications."

Galaxy discussed the project with many expert sources
on Carbogel.

At that time, investigation showed that the consensus
was that it was still untried on a commercial scale. Also,
it was reported to be closely related to the MURF tech-
nology. The people at Studsvik said then this was essent-
ially a paper process. They said they have been unable to
obtain any data of successful experimental results. They
described MURF, which had some firing trials in a small
scale of about 1 megawatt. The MURF they described as a

slurry containing coal, water and oil. Carbogel now wants to make another step to handle coal in the burner so they can retrofit old oil-fired burners, to keep the ash in a fluid phase and remove it as a liquid. However, they point out that Combustion Equipment Association of New York City had somewhat the same process.

In late 1980 Galaxy reported significant progress had been made in the development of Carbogel at Scaniainventor.

Mr. S.O. Rosby of Fläkt confirmed that the Carbogel development work has proceeded from a bench scale to a demonstration scale of 5 MW.

A 5 MW plant was in the state of completion in Helsingborg and expected to go on stream in early 1981. The dust collectors are supplied by Fläkt.

Björn Olsson stated that Scaniainventor has now run a 3 MW burner in air, in a flame tunnel, successfully for a year.

Scaniainventor developers of the process, and Boliden have formed a new company named "Carbogel" with equal shares (50:50) in order to develop and market the process.

Fuel processing is used to remove the sulfur. The unspecified additive* is used to improve the fuel processing and to reduce the water content. The desired water content below 20% has not been achieved and is considered as not feasible. Even though the achieved fuel properties are inferior to those optimistically reported to Galaxy earlier, "Carbogel" is quite happy about their laboratory results and is foreseeing a broad applicability of this invention.

As the Carbogel company is newly formed, the contacts between Scaniainventor and Bolidan, who will contribute the fuel cleaning technology, have been limited. No policy decision on release of information to DOE has been made. Managing Director of Boliden, Mr. Falström insured us though, we would receive an answer to our inquiry.

*Undoubtedly a surfactant. Carbogel has been very reluctant to release any hard information during the past three years.

New Managing Director of Carbogel AB, Mr. Par Bunke stated:

- Carbogel is interested in DOE contacts, presently only cooperating with EPR on coal-water-slurries, some contacts to U.S. utilities.
- Carbogel is intending to approach U.S.A. by formation of U.S. company. They are looking for potential U.S. partner (on a 50/50 participation level) to market and to issue licenses, also for spin-off products.
- 25 Tons of Carbogel was produced in August 1980. It is of prime quality, to be used in a 5 MW plant in Helsingborg. Medium grade Carbogel was also produced. This was intended for gasification trials (production of ammonia) at Boliden subsidiaries. Mr. Bunke stated the "tests were successful."

- 500 Tons of Carbogel were thought to be produced in November 1980, to be tested in Boliden industrial burners. 200 Tons of this are to be tested for gasification use.
- 5,000 Tons are to be produced in spring 1981 for 20 MW burner under development in Helsingborg.

Carbogel has made the difficult transition from a paper process to semi-commercial production and use. Galaxy recommends the Office of Coal Utilization follow-up on future developments.

Finland

In Finland, the Energy Department is working on a mixture of peat powder and oil. This work, however, turns out to be in the paper stage only.

The work of Dr. Korpela of Ekono in simultaneous firing of oil, wood and waste liquors in paper plants was mentioned earlier in this report.

In summation, the earlier reports on COM and water slurries in overseas nations was viewed with skepticism, both overseas and in the U.S.

However, by 1981, favorable results were being reported both overseas and here, and DOE's Coal Utilization Office stepped-up developmental work here, which have confirmed Galaxy's overseas reports that coal-water slurries burn more like oil than coal. Thus, these mixtures of replacing oil in boilers designed for oil, with a "stretch" possible to replace gas. This, coupled with the European developments in efficient, residence sized boilers would carry out the claims of overseas developers.

Internal Combustion Engines

In the early stages of the work, Galaxy was asked to survey rapidly the status of stratified charged engines. The work in Japan (now well covered by others) was outlined. In addition, the Swiss, German, and Scandinavian studies, primarily composed of computer modeling were reported.

Coal Tar Burning Diesel Engines

Late in 1979, DOE requested information on the reported development of diesel engines burning coal tar by Mitsui Shipbuilding and Engineering Company.

Specific information was sought to determine whether this was a paper study or an actual commercial development - if so, what size; nature of coal derived fuel; whether pretreated; whether special lubricating oils were required and also was Mitsui amenable to licensing.

Galaxy - NJM in Tokyo reported the following:

1. Mitsui had tested a 750 HP diesel for half a year.
2. Bore diameter is 420 MM, stroke 460 MM.
3. Commercial size will be same bore and stroke, but consist of 6 to 18 cylinders.
4. Mitsui says, "this is a proven practical technology".
5. Coal tar used is coke oven by-product from which the sludge is removed by centrifuging at a temperature below 100°C.
6. Mitsui has developed special lubricating oil of its own for use in this engine.
7. Mitsui is studying additional low quality fuels, dual fuel, etc., in addition to coal tar.
8. Galaxy determined that licensing negotiations were possible with Mitsui, which, however, intends licensing not only coal tar, combustion technology and lubricating oil, but total license, including engine design, etc.

DOE's Heat Engine Branch requested additional information on emissions, particularly NO_x characteristics and the characteristics of the fuel, especially fuel bound N.

Galaxy immediately sent a telex to our Tokyo office requesting the answers to the foregoing questions.

The following telex reply was received.

"DIESEL ENGINE

CURRENTLY JAPANESE EPA REQUIREMENTS AGAINST NOX ARE NOT REGULATED FOR DIESELS BECAUSE OF SMALL SCALE POWER GENERATION SYSTEM.

HOWEVER, TO MEET LOCAL CONTROLS ON TOTAL EMISSION, DRY DENITRIFICATION SYSTEM WAS INSTALLED FOR NOX REDUCTION TESTS WITH EXHAUST CIRCULATION PROCESS AND WATER SPRAY PROCESS. BOTH PROCESSES REDUCED HEAT EFFICIENCY.

CAPITAL COST OF DENITRIFICATION SYSTEM ACCOUNTS FOR APPROXIMATELY 20 PERCENT OF TOTAL DIESEL GENERATION FACILITY WHILE OPERATING COST INCREASES BY ABOUT 3 PERCENT.

"5000 KW SCALE DIESEL GENERATION USING RESIDUAL
OIL WILL GO ON STREAM JULY 1980 IN YOKKAICHI
PETROCHEMICAL COMPLEX SITE."

On February 4, 1980, Galaxy made arrangements for a group of Mitsui experts from Japan, headed by Dr. Mikihiko to meet with Mr. John Fairbank at Germantown for a full discussion of the Mitsui project.

No follow-up was requested on the license negotiations. A copy (in English) of the "Development of Mitsui L & V42M Diesel Engine" was submitted, and is included by reference.

This completed this phase of Galaxy's task.

Coal Dust Burning Diesels

The interests in this subject became quiescent until 1980 when the Bundesverband der Luftfahrt Zubehr und Raketenindustrie EV of Hamburg, Germany, scheduled a meeting on the subject of coal-fired diesels. The meeting was not held, apparently due to the fact that the engines to be displayed were not completed.

The previous comprehensive report received by DOE on coal-fired diesels was in 1976. Mr. Erich Soehngen, considered the world authority on this subject, who prepared the earlier report, was retained by Galaxy. When the conference was not held, Galaxy's Hamburg associates prepared a brief survey of the state-of-the-art of European R&D on coal-dust-burning diesel engines.

European R&D managers, officials and senior experts with experience in the area of coal-based fuels for diesel engines were interviewed.

This brief survey showed the following:

- Germany, Denmark and Switzerland are carrying on work in coal-burning diesels.
- In the U.K. relevant work has recently been stopped.
- The Bundesverband der Luftfahrt Zubehr und Raketenindustrie (BLR) claimed to have a coal processing system and an engine ready for large quantity production within a short time. However, no reliable details about the state and significance of this work could be found.
- Experts are generally extremely skeptical about the technical data and substance of the widely publicized claims of the BLR.
- There is a conclusion drawn by many that the claims of BLR are primarily to obtain support of the BMFT for a conference to focus further interest on this matter.

The coal dust fired diesel engine appears technically feasible, particularly for use in stationary and low-speed applications. However, the consensus is that it is not economical at the present time, but may provide a way of decreasing oil imports.

Significant development work is necessary, particularly in the further development of coal-oil slurries and other forms of coal suspensions. This work will be particularly directed at ash-free coal, and further processing of the coal in order to diminish erosion due to the particulate matter.

The development of coal-oil mixtures for high-speed engines suitable for vehicles is definitely in the future. The R&D includes reducing the sulfur content from 1% to below .6% and the ash level to below .05%.

It was Galaxy's conclusion that significant advances of the coal dust engines will not be achieved by BLR in the near future due to lack of support by the BMFT and others. The BMFT added that "the use of solid coal products in vehicular diesel engines will hardly gain much significance, and only the liquid products from coal conversion are expected to deserve consideration."

Mr. Soehngen reviewed the report prepared by Galaxy-Planco in Hamburg in March, 1981.

It was his opinion that the report fairly reflected the situation.

He had subsequently communicated with the Bundesverband der Luftfahrt Zubehr und Raketenindustrie (BLR). He had gathered from them that their interest was no longer in holding an International Conference. This was primarily to focus interest on the subject. He described the literature provided by the BLR as promotive.

BLR told him they held options on "millions of Deutschmarks worth of coal burning diesel engines", which lacked only the financing to start production on the engines.

However, there was no data made available to Mr. Soehngen, to Galaxy-Planco, Hamburg, or to Galaxy, Washington to indicate there were actually engines advanced over those of the World War I vintage, ready to go into production, or that a firm market existed to absorb such engines if produced.

The full report (subtask #013) is included by reference.

In Switzerland, Gebruder Sulzer feel that coal-dust burning diesels are not to be as favorably considered as coal-oil slurries which are a far better alternative. Sulzer claims that the main problems of slurry injection (such as erosion and jamming) have been fundamentally solved. Again, they feel that the economics are still currently questionable due to low specific efficiencies. However, once diesel engines have been adapted to slurries, the coal-dust engine might be the next step.

Doxford Engineering in the U.K. reports they have an engine which they consider essentially suited for operation with coal fuels. However, due to the depressed state of shipbuilding in the U.K., all work has ceased on this.

The only remaining nation which had been working on coal-fired diesels was Burmeister and Wain of Denmark. Their interest was acquired by MAN of Germany, and B&W Diesel Division will work on the large two-cycle stationary and marine diesels.

They are doing development work on coal-fired diesels in close cooperation with DOE, mainly involving coal-dust slurries and samples from the SRC₂ process. This work is being carried on directly with DOE.

Mr. Erich Soehngen, retained by Galaxy, was asked to comment on the above findings. He stated that the report concurred with his knowledge of the field. His full report (part of Task #013) is included here by reference.

Galaxy concurs with the opinion of the Contract Officer, who feels there is little future in the coal dust engine, favoring fuel to be supplied either by coal oil slurries using de-ashed coal or coal liquefaction products.

Improved Oil & Gas Burners for
Industrial & Commercial Applications

Investigation of these technologies were assigned to Galaxy in connection with widely separated tasks in widely separated nations. Many of the findings are covered in such sections as "fluidized bed combustion", "small boilers", etc. However, for clarity, the remaining tasks in this field are assembled here for ease of comparison.

Japan

In Japan, development of technologies in this field had initially been through users taking the lead in the R&D work assisted by manufacturers so that technical know-how could be kept secret.

However, furnace manufacturers, including Chugai Ro Kogyo Co., Ltd.; Nippon Furnace Kogyo Co., Ltd.; Mitsubishi Heavy Industries Co., Ltd. originally introduced technologies from overseas, but succeeded in adding various improvements to their original furnaces, and consequently are able to provide users with advanced technologies.

Japanese technical development is presumed to be the most advanced in pollution control because it is required to meet domestic environmental regulation standards, which are now stricter than those in the U.S.

Some special governmental programs deserve attention. MITI's Agency of Industrial Science and Technology, in their Moonlight Program, started a development program on glass fusion furnace (which was begun in April, 1978) and on infrared radiant furnace (which was begun in April, 1979) in an attempt to attain energy saving in the furnace itself.

The R&D for the fusion furnace was carried out in the Governmental Industrial and Technical Research Institute of Osaka. R&D efforts were exerted to make the immersion combustion method applicable to the glass fusion furnace in place of the surface heating method presently applied to fuse glass.

This institute is now also performing R&D on a new clarification (defoaming) method.

The R&D for infrared radiant furnace has been performed at the Governmental Industrial and Technical Research Institute at Nagoya.

Aimed at saving energy for the drying and calcining steps in the pottery manufacturing industry, this R&D effort was initiated to work out an efficient infrared radiation medium using ceramic materials and also to establish the measuring methods related to such a medium.

Coating such a medium with ceramics would reduce conversion of energy to light and increase effective infrared radiation, resulting in energy savings.

On the other hand, the Agency of Industrial Science and Technology has no projects on general industrial furnaces which use oil as fuel.

Studies by governmental organizations are limited. Small studies on furnace types are performed by Governmental Industrial and Technical Research Institute of Osaka and some incidental burner study has been done by the Research Institute for Pollution Control and Natural Resources.

R&D work is being carried on in gas/oil type heaters and burners by private sector companies including Takuma Co., Ltd.; Ishikawajima-Harima Heavy Industries Co., Ltd.; JGC Corporation (formerly Japan Gasoline Co., Ltd.). Additional studies have been made by Mitsubishi Heavy Industries, Ltd.,; Hitachi, Ltd.; and Daido Steel Co., Ltd.

The current actual situation is that most of those firms have reached the state of commercializing such furnaces as can attain 20%-30% more energy saving than existing conventional industrial ones.

For industrial furnaces, the target for energy saving has concentrated on:

1. Waste heat recovery.
2. High temperature and high efficiency combustion.
3. Prevention of thermal radiation to the outside of the furnace.
4. Reduction of excess air ratio.
5. Improvement of furnace structure.

High-Temperature High Efficiency Combustion

This method is designed to elevate the temperature inside the furnace up to 2,000°C which is close to the theoretical value.

Mitsubishi Heavy Industries have been exerting particular effort on this method with a structure which uses such materials as refractory brick and ceramics in the furnace wall and heating resistant metals (based on Ti, Ni and W) in the heat transferring part.

However, at the present, sufficient results have not yet been obtained due to problems involved in availability and cost of material. Their method is still at the R&D stage.

Reduction of Excess Air Ratio

This method is aimed to attain high-temperature combustion by reducing excess air and burning fuel at an appropriate fuel-air ratio (from the viewpoint of combustion efficiency).

This had been actively studied by Ishikawajima-Harima Heavy Industries; Mitsubishi Heavy Industries; Sumitomo Shipbuilding & Machinery, etc., but has been abandoned due to the increase of NO_x which accompanied the higher temperatures.

Improvement of Furnace Structure

This method is aimed to attain energy saving by modifying the furnace structure itself.

All of the proposals which have been offered include changing the shape of the heat transfer tubes and thereby enlarging their surface area.

Governmental Industrial Technology Research Institute of Hokkaido which belongs to Agency of Industrial Science and Technology (MITI) has issued a report which merely confirms that a fluidized bed would give minimum 30% more energy saving than a fixed bed.

However, the Hitachi Shipbuilding & Engineering Co., which has a commercialized fluidized bed furnace, reached an energy saving rate of about 20%, indicating a need for still further study. This 3 meters in inside diameter, atmospheric bed furnace is now on sale for combustion of sewage sludge.

Japanese specialists in the field told Galaxy in 1981 that an AFB furnace, attaining an energy saving of about 30% would be able to be put into practical use in 4-5 years.

Heating Furnace of Fluidized Bed Type

Among government-run and other, public research organizations, Governmental Industrial Technology Researching Institute of Hokkaido have been studying a heating furnace of fluidized bed type on a bench-scale basis.

However, this has not been included in the themes under "Moonlight Project", but those under "Sunshine Project", because its main purpose is to develop a furnace of new type.

Under this study, aluminum pellets are packed in a stainless steel furnace which is 10 cm in inside diameter and 3m in length.

In this system, ore, metal or water, etc., fed into the furnace evaporates while fluidization is taking place in the bed of pellets heated by combustion of fuel gas or heavy oil. High thermal efficiency is obtained since combustion heat is transferred by direct contact with the pellets.

In turn, direct contact of the hot fluidized pellets with the material to be treated results in an excellent furnace efficiency.

According to Governmental Industrial Technology Research Institute of Hokkaido's tentative calculation based on data from a bench-scaled furnace and assumption of waste-gas furnace with an operating rate of $1000 \text{ m}^3/\text{hr}$, has been calculated that the furnace of the fluidized bed type is 30% higher in energy saving rate than that of the fixed bed type.

This R&D work on the fluidized bed furnace for coal gasification is scheduled to be expanded by participation of such major domestic concerned firms as Mitsubishi Heavy Industries; Kawasaki Heavy Industries and Babcock-Hitachi K.K., with Governmental Industrial Technology Research Institute of Hokkaido as the leader.

In this work, a pilot test of the PBF furnace under a pressure of 20 atm will be carried out using 500-700 mm diameter size.

This pilot plant with a capacity of about 20,000 m³/day of total gas produced (or 7,000 m³/day of methane) is scheduled to be put in operation in 1981-'82.

Tubular Furnace

JGC Corporation (formerly Japan Gasoline Co., Ltd.) have developed and commercialized a tubular furnace, reducing excess air ratio, decreasing heat radiation loss from the furnace wall and attaining recovery of heat from waste gas.

The tubular furnace with a heat absorption capacity of 30×10^6 kcal/hr, uses oil.

In an existing equipment, excess air ratio is 40% and stack temperature is 500°C . A comparison is shown in the following table:

<u>Excess Air Ratio</u>	<u>Stack Temperature</u>	<u>Thermal Efficiency</u>
40%	500°C	70%
30%	480°C	72%

Reduction of excess air ratio to 30% resulted in 2% increase in thermal efficiency. The resultant energy saving was 1.20×10^6 kcal/hr, which would lead to an annual saving of fuel cost of $\$0.134 \times 10^6$ (with 8,000 operating hours per year).

Besides JGC Corporation, Takuma Co., and Mitsubishi Heavy Industries have also done similar calculations and based on their results, have entered into commercialization. There is purposeful vagueness on the part of these companies in identifying the attainments of those manufacturers. It has been impossible to clearly recognize whether each R&D project is now at the final stage or still being directed toward a bigger target.

Energy Saving Low NO_x Combustion Method

Japanese public pressures has forced Japanese industry to cope with the NO_x environmental regulations, now stricter than those imposed in any other country. Various technologies have been developed and put into practical use, on the basis of such principles as:

1. Lowering combustion gas temperature.
2. Decreasing oxygen content in combustion gas.
3. Shortening gas detention time in flame.
4. Decreasing nitrogen compounds in fuel.

Different combinations of methods have been combined depending on the type of burner. Those now in use in Japan are:

1. Combustion under slowed mixing
2. Acceleration of mixing
3. Addition of steam, water, etc. to liquid fuel.
4. Recycle of exhaust gas.

There are burners of the above types which have already been commercialized.

Nippon Furnace Kogyo Co., Ltd. has developed its "Low Excess-Air Combustion System by O₂ Trimming Control" as a low NO_x energy saving combustion method. This system, now showing effectiveness as a combustion unit for boilers, has been completed on the basis of domestic improvements added to Western technologies. It is reported that Nippon Furnace Kogyo has obtained a technical license from TRW company concerning the low-oxygen combustion method and acquired the basic concept for the O₂ trimming system from C.E. Company.

Future R&D is planned. Japan Flame Research Foundation will be established by iron and steel, gas and other related firms with Nippon Furnace Kogyo as the leader to promote a closer technical exchange with overseas research and development organizations. A linkage with DOE was suggested to Galaxy.

European Advanced High Efficiency Combustors

The work was investigated in each country surveyed.

The majority of answers by the European governmental research agencies were, "that is a matter for the private sector". In the private sector, many organizations claimed dramatic breakthroughs. However, these claims appeared overstated in many cases, and are subject to verification, as the purveyors, of course, only cited those characteristics which put their products in the most favorable light.

A case in point, is the development of a fluidized bed gas or oil residential size burner in the Netherlands, mentioned earlier in this chapter.

Rolph Collin's work at the Royal Swedish Institute on flat non-swirl blue flame burners, and heat transfer systems to steel ingots was also discussed earlier. He now claims 25 ppm NO_x, feeding his burner on light oil and 50 ppm on heavy fuel oil (comparable to American #5). He is feeding his burner with pulverized coal and with coal-oil mixtures, and coke overgas, still claiming the advantages of better heat transfer.

The Swedish program at Studsvik to burn shale in a fluidized bed, has been shut down due to a variety of reasons, mainly the extremely high sulfuric content of the stack gas.

At the Danish Technical University, Professor Hadvic has developed a small oil burning nozzle, which can operate down to .7 liters per hour (.18 U.S. gallons). It is based on his previous studies of fluidics and described as an oscillator nozzle, non-sensitive to fuels and can be utilized for injecting water droplets, which he claims other nozzles of similar size can not do.

Professor Hadvic is also working on a 1/2 kilo per hour blue flame oil burner, to be used in a two temperature residential burner. It is a rather simple stack gas heat exchanger, converting 40°C water into 70°C heat out, producing a claimed 20% increase in heat recovery.

In the Netherlands, Harmson BU (in the private sector, working in conjunction with the quasi-governmental research organization, TNO) has worked on a residential size fluidized bed combustor. This one cubic foot sized combustor has a claimed increased efficiency, which on analysis is mainly due to the automatic damper effect of the fluidized bed material when the flame is cut off.

Also, in the Netherlands, Smit Ovens Nijegen B.V. claims an "Ultramizing" oil burner produces a clean and sootless flame. Although it burns oil, they claim the flame has the characteristics of a gas flame, due to the oil atomizer, which uses the combustion air as the atomization medium.

Smit Ovens states this burner can produce fuel savings up to 15%.

This burner could be used in any oil-fueled industrial heating process requiring clean heat.

In Germany, the Saarberg work, cited elsewhere in this report and reviewed by DOE officials subsequent to Galaxy's report, appears to be the most advanced in that country.

France is doing little advanced work in oil and gas burners, due to reasons stated earlier.

Italy, Spain and Portugal are mainly following work elsewhere in this field, mainly through local subsidiaries of B&W, CE and other U.S.A. firms. The private sector firms presented their work to Galaxy. The data substantiated the above observation. Work in the U.K. was specifically exempted from Galaxy's assignment. All specification sheets have been transmitted to DOE.